CHAPTER 13
FLUIDIZED BED BOILERS

13-1. Fluidized bed boilers.

a. Fluidized bed combustion has now progressed through the first and into the second and third generation of development. Fluidized bed technology is not new but has been revived in this country because of fuel costs and the availability of poor quality fuels. Commercial and industrial power plants now have a third type of solid fuel boiler to consider for steam requirements. Economics, fuel pricing, availability of low grade fuels and environmental considerations have made the fluidized bed boiler a viable option to evaluate along with the stoker or pulverized coal fired units. The units can with care be designed to burn a number of fuels including low grade coals, lignite, coal mine wastes (culm), refinery gas, woodwastes, waste solvents, sludge, etc.

b. Fluidized bed combustion offers the ability to burn high sulfur coal and meet environmental requirements without the use of scrubbers. The mixture of fuel and limestone is injected in such a way that the fuel and limestone are distributed across the bed. The fuel and limestone are kept in turbulent motion by upward air flow from the bottom of the furnace. The furnace combustion takes place at about 1550 degrees Fahrenheit to 1750 degrees Fahrenheit. Control of sulfur dioxide and nitrogen oxide emissions in the combustion chamber without the need for additional control equipment is one of the major advantages over conventional boilers.

13-2. Types of fluidized bed boilers.

a. Fluidized bed boilers cover a variety of systems. There is no unique design. An industrial fluidized bed boiler could assume several possible configurations depending on such factors as bed pressure, the choice between natural or assisted circulation, the gas velocity in the bed, fuel and air distribution systems, bed design and method of achieving high carbon utilization and control of sulfur dioxide.

b. There are four types which will be given consideration for control of sulfur dioxide and nitrogen oxide emissions. These are shown in figure 13-1 and size is also compared for a 50 million Btu/hour heat imput unit.

c. The types can further be demonstrated by comparing them as stationary fluid bed (bubbling bed) or circulating bed designs. To determine this type, the relationship between the gas velocity and the differential pressure in the fluidized bed must be established. Figure 13-2 shows this relationship for various bed designs.

d. The fluidized bed is a system in which the air distributed by a grid or distribution plate, is blown through the bed solids developing a "fluidized condition." Fluidization depends largely on the particle size and the air velocity. At low air velocities, a dense defined bed surface forms and is usually called a bubbling fluidized bed. With higher air velocities, the bed

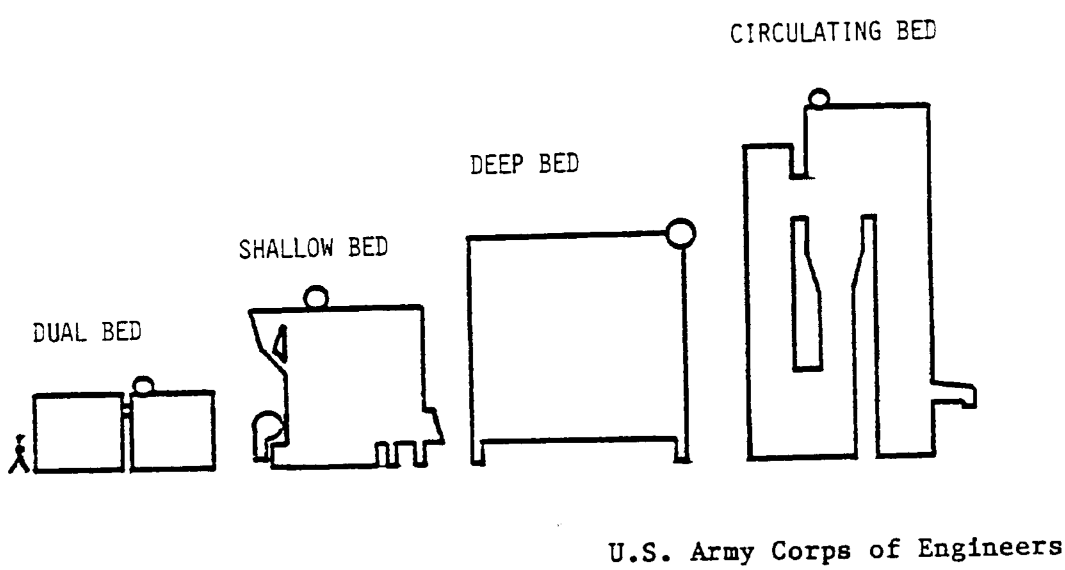


Figure 13–1. Types of fluid bed combustors size comparison

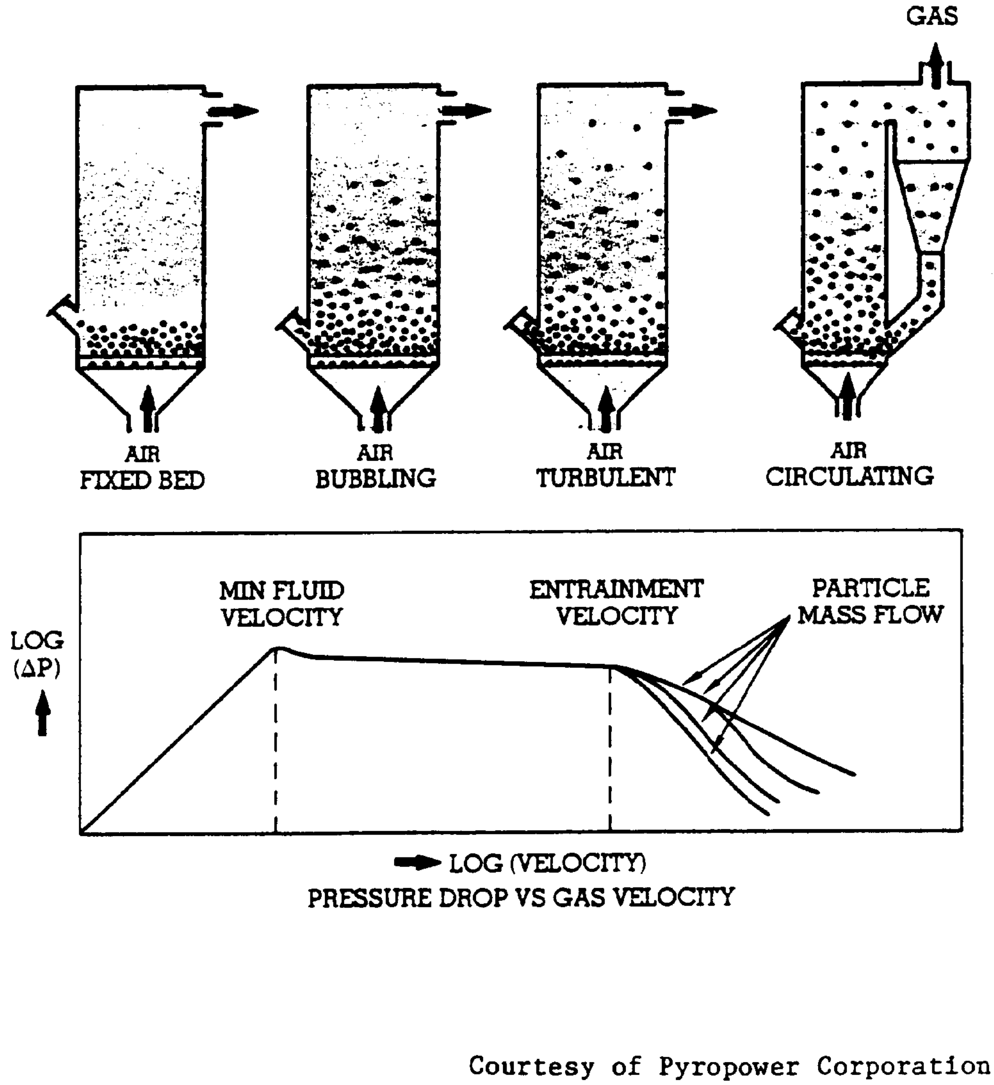


Figure 13-2. Pressure drop vs. gas velocity

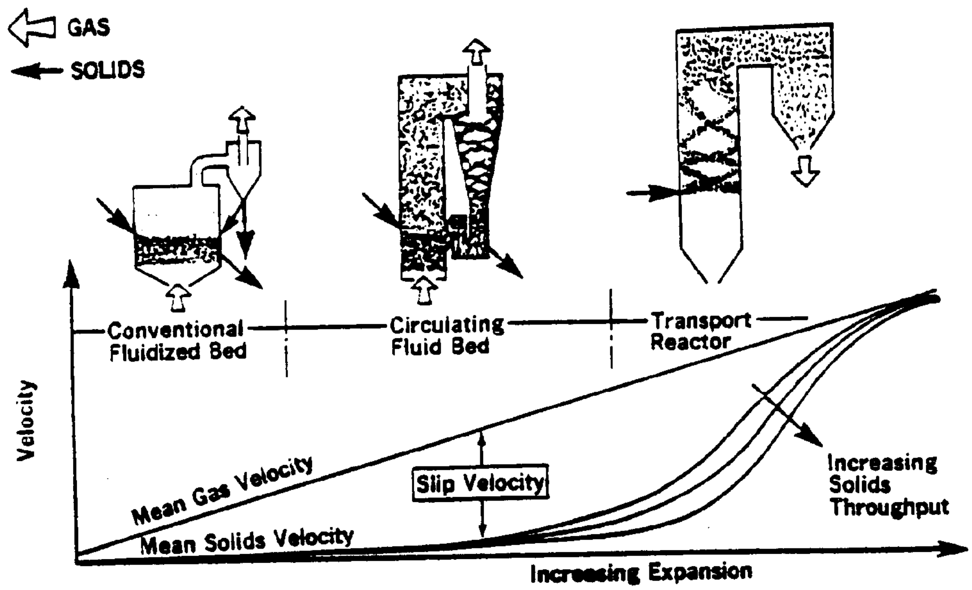
particles leave the combustion chamber with the flue gases so that solids recirculation is necessary to maintain the bed solids. This type of fluidization is called circulating fluidized bed.

e. The mean solids velocity increases at a slower rate than does the gas velocity, *as* illustrated in figure 13-3. Therefore, a maximum slip velocity between the solids and the gas can be achieved resulting in good heat transfer and contact time with the limestone, for sulfur dioxide removal. When gas velocity is further increased, the mean slip velocity decreases again. These are the operating conditions for transport reactor or pulverized coal boiler. The design of the fluidized bed falls between the stoker fired boiler and the pulverized coal boiler using the bed expansion.

f. The shallow fluidized bed boiler operates with a single bed at a low gas velocity. A shallow bed minimizes fan horsepower and limits the free-board space. The bed depth is usually about 6 inches to 9 inches and the free-board heights are only four to five feet. Desulfurization efficiency of a shallow bed is poor, with only about 60 to 80 percent removal, because SO_2 does not have adequate time to react with the limestone before moving out of the shallow bed. The shallow bed fluidized boiler is of the bubbling bed design. The shallow bed will be of very limited use because of its poor sulfur dioxide removal.

g. A deep fluidized bed boiler is a bubbling bed design.

(1) The bed depth is usually 3 feet to 5 feet deep and the pressure drop averages about one inch of water per inch of bed depth. The bulk of the bed consists of limestone, sand, ash, or other material and a small amount of fuel. The rate at which air is blown through the bed determines the amount of fuel that can be reacted. There are limits to the amount of air that can be blown through before the bed material and fuel are entrained and blown out



Courtesy of Combustion Engineering, Inc.

Figure 13–3. Velocity vs. bed expansion

of the furnace. Conversely, when air flow is reduced below the minimum fluidizing velocity, the bed slumps and fluidization stops.

(2) The fuel feed systems available are either under-bed feed system or over-the-bed feed system. The under-bed feed system is quite complex. It requires coal at less than 8 percent surface moisture and crushed to about 6 MM top size to minimize plugging the coal pipes. Operating and maintenance costs are usually high for the under-bed feed system. The major advantage of the under-bed feed system is that with use of recycle combustion efficiency approaches 99 percent. The over-bed feed system is an adaptation of the spreader stoker system for conventional boilers. This system has a potential problem of effective carbon utilization. Carbon elutriation can be as high as 10 percent.

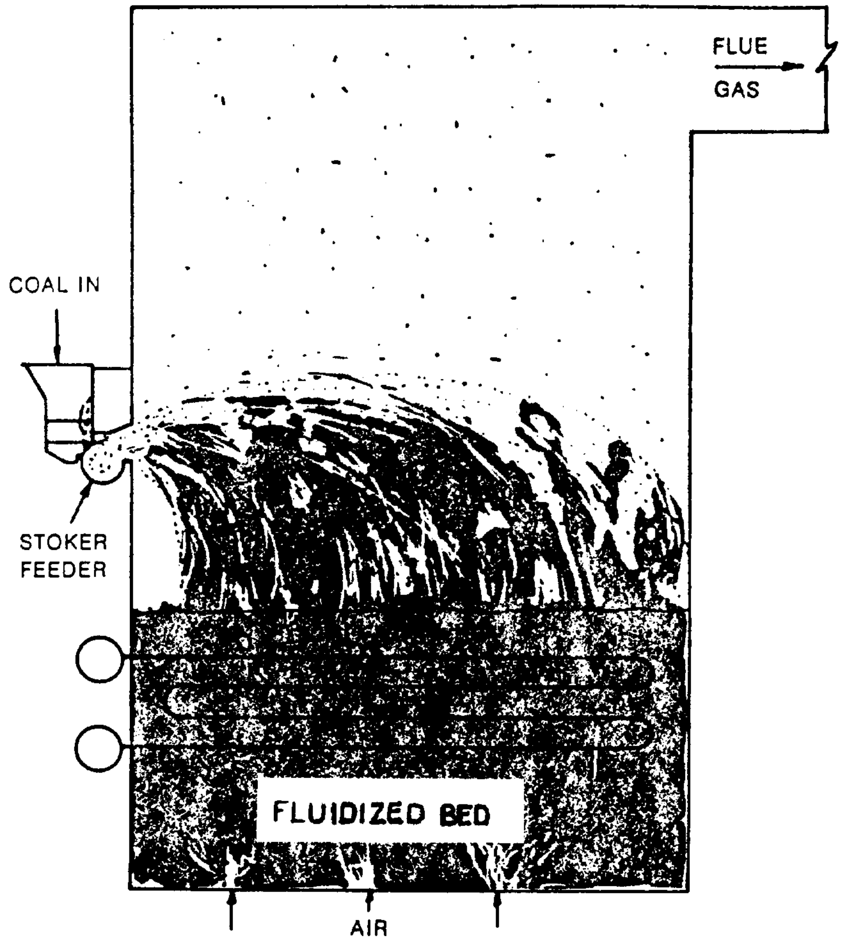
(3) Some bubbling bed units have sectionalized or modular design for turndown or load response. This allows a section to be cut in or out as required. Some are actually divided with water cooled or refractory walls. This type unit should be matched to the facility demand pro-file to avoid continual bed slumping and operator attention. When continuous stopping of sections is required to control load for extended periods, the fluidized bed boiler may become a big user of auxiliary fuel to maintain bed temperature.

(4) Major limitations of the bubbling bed design are high calcium/sulfur ratios, low combustion efficiency, limited turndown without sectionalization of the furnace bottom and complexity of the under bed feed system required to minimize elutriation of unburned fines. Typical fluidized bed combustors of this type are shown in figures 13-4 and 13-5.

h. In the circulating fluidized bed boiler, the fuel is fed into the lower combustion chamber and primary air is introduced under the bed.

(1) Because of the turbulence and velocity in the circulating bed, the fuel mixes with the bed material quickly and uniformly. Since there is not a definite bed depth when operating, the density of the bed varies throughout the system, with the highest density at the level where the fuel is introduced. Secondary air is introduced at various levels to ensure solids circulation, provide stage combustion for NO_x reduction, and supply air for continuous fines combustion in the upper part of the combustion chamber.

(2) Combustion takes place at about 1600



Courtesy of Foster Wheeler Energy Corporation

Figure 13–4. Bubbling bed boiler I

degrees Fahrenheit for maximum sulfur retention. The hot gases are separated from the dust particles in a cyclone collector. The materials collected are returned to the combustion chamber through a nonmechanical seal, and ashes are removed at the bottom. The hot gases from the cyclone are discharged into the convection section of a boiler where most of the heat is absorbed to generate steam. Typical fluidized bed boilers of this type are as shown in figure 13-6.

(3) Major performance features of the circulating bed system are as follows:

(a) It has a high processing capacity because of the high gas velocity through the system.

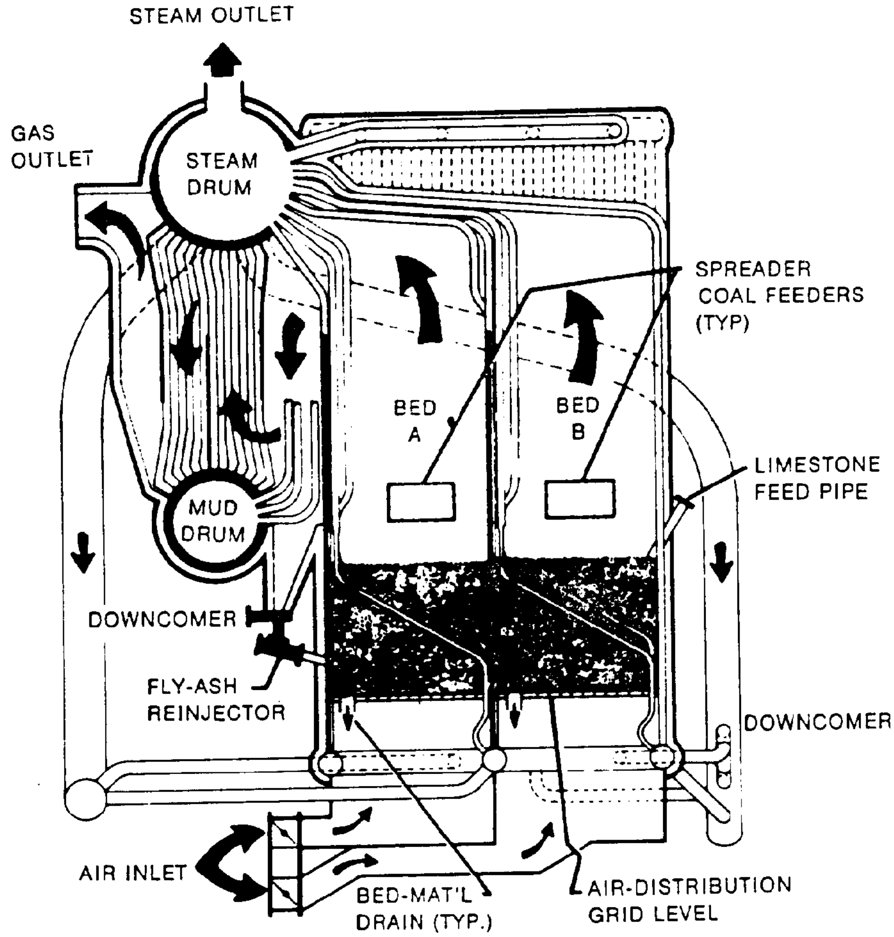
(b) The temperature of about 1600 degrees Fahrenheit is reasonably constant throughout the process because of the high turbulence and circulation of solids. The low combustion temperature also results in minimal NO_x formation.

(c) Sulfur present in the fuel is retained in the circulating solids in the form of calcium sulphate soit is removed in solid form. The use of limestone or dolomite sorbents allows a higher sulfur retention rate, and limestone requirements have been demonstrated to be substantially less than with bubbling bed combustor.

(d) The combustion air is supplied at 1.5 to 2 psig rather than 3-5 psig as required by bubbling bed combustors.

(e) It has a high combustion efficiency.

(f) It has a better turndown ratio than bubbling bed systems.



Courtesy of Foster Wheeler Energy Corporation

Figure 13–5. Bubbling bed boiler II

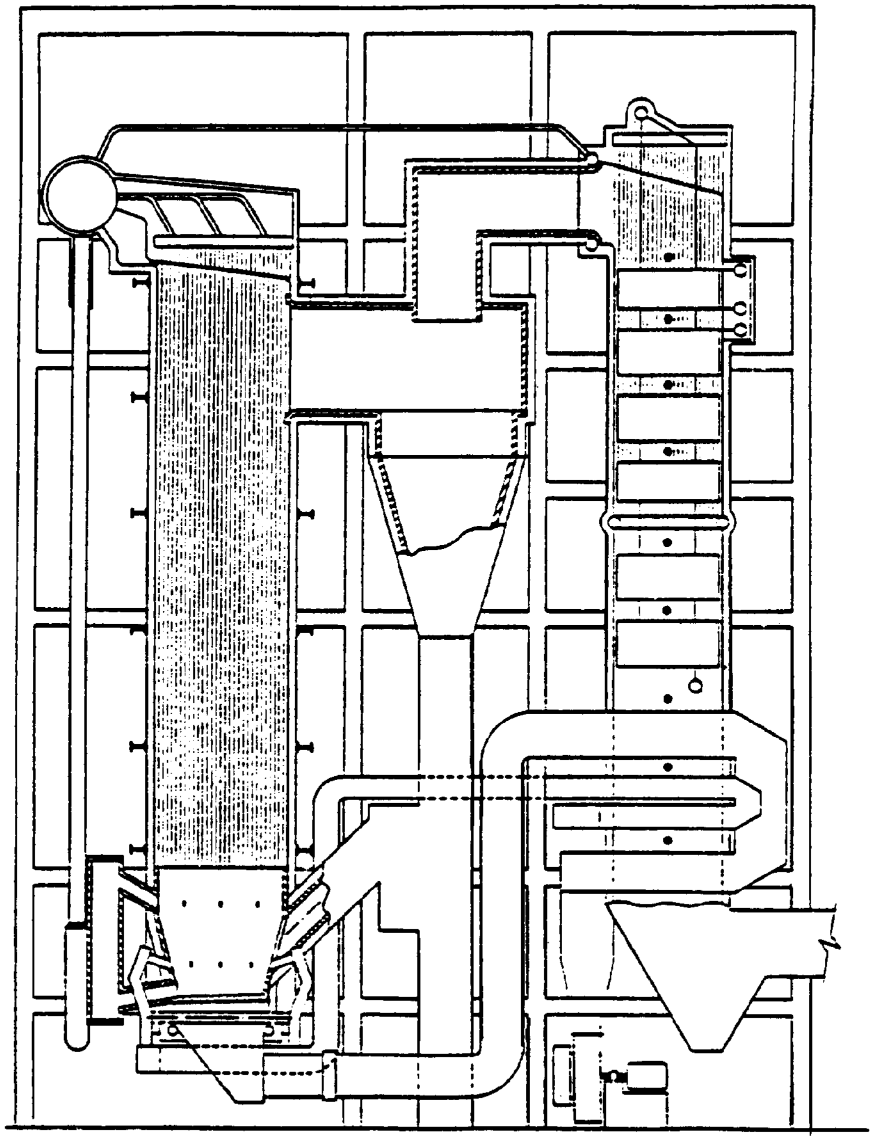
(g) Erosion of the heat transfer surface in the combustion chamber is reduced, since the surface is parallel to the flow. In a bubbling bed system, the surface generally is perpendicular to the flow.

i. In the dual bed fluidized combustor, combustion and desulfurization take place in two separate beds, allowing each different reaction to occur under optimal conditions.

(1) The lower bed burns coal in a bed of sand, fluidized from below by the combustion air and gases, and maintained at a steady equilibrium temperature by the extraction of energy through in-bed steam generator tubes. The bed depth is more shallow than the conventional bubbling bed design.

(2) The flue gas then travels through an upper bed of finely ground limestone where desulfurization takes place. The dual bed design allows coals to be burned at about 1750 degrees Fahrenheit while desulfurization takes place at about 1550 degrees Fahrenheit. The upper bed also serves to catch unburned coal particles that may have escaped to complete combustion of any unburned carbon.

(3) A dual bed can be utilized on capacities up to 200,000 pounds per hour of steam. The major advantages are: shop fabrication; can be retrofitted to some existing oil and gas fired boilers; enhanced combustion efficiency by allowing the lower bed to operate at 1750 degrees Fahrenheit; lower free-board heights required; and better load following. A typical dual bed fluidized combustor is shown in figure 13-7.



Courtesy of Pyropower Corporation

Figure 13–6. Circulating fluid bed boiler system

13-3. Applications

a. Fuel Application.

(1) A wide range of high grade and low grade fuels of solid, liquid or gaseous type can be fired. The primary applications are fuels with low heating value, high sulfur, waste materials, usually the least expensive. Fuel can be lignite, coal washing waste (culm), high sulfur coal, delayed petroleum coke, or waste material that would not burn satisfactorily in a conventional boiler. The fluidized bed boiler has the ability to burn most any residual fuel and reduce emissions by removal of sulfur compounds in the limestone bed.

(2) A complete evaluation of fuels to be burned should be given consideration in selection of the equipment. Many factors including heating value, moisture, ash fusion temperature, sulfur content, and ash content will affect the system configuration.

(3) Fuel sizing is important. For coal it is recommended that it not be run-of-mine. It should be crushed to avoid large rocks and pieces of coal causing problems in the bed. Coal sizing is important and will vary with each fluidized bed manufacturer. Typically, sizing will vary from 0 — ¼ inch x 0 for overfeed systems to ¼ inch x 0 for underfeed systems.

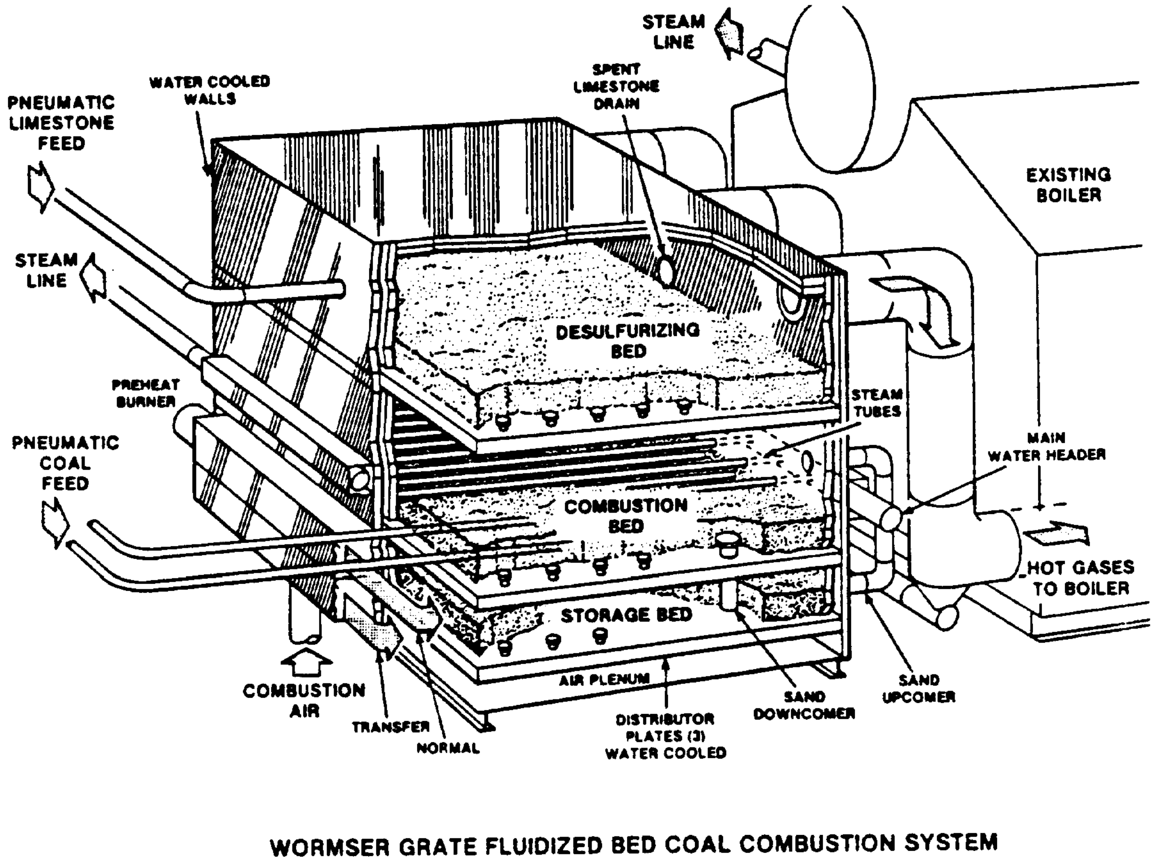


Figure 13–7. Dual bed fluidized bed boiler

b. Process application.

(1) The fluidized bed can be utilized to control SO_2 emissions when high sulfur fuels are used. Also reduction of SO_2 emissions can be achieved when nonattainment areas are looking for additional steam for process. The capability of fluidized bed combustion to control emissions makes this technology particularly suited for applications where stringent emissions control regulations are in effect.

(2) Steam generation in a fluidized bed boiler versus a conventional boiler will not be economical when using compliance coal for control of sulfur dioxide emissions. However, several studies indicate that fluidized bed boilers are competitive with conventional coal fired boilers that include flue-gas desulfurization systems. Facility location may dictate Best Available Control Technology (BACT) be used to control SO_2 and NO_2 emissions.

(3) Nitrogen oxide emissions can be controlled with a fluidized bed boiler. The fluidized bed boiler generates very little thermal nitrogen oxide because of the low temperature of operation.

(4) Pressurized fluidized bed boilers continue in research and development. Higher efficiency designs for utility applications involve considerably higher initial costs and design complexity. Also, a cost effective way to clean up the hot flue gases before they reach the turbine has not been found.

(5) The fluidized bed boiler can be used to incinerate low grade fuels that would be normally considered waste residues.

13-4. Fluidized bed performance

a. With the exception of a baghouse or precipitator, which is required for particulate removal, additional gas cleaning devices are not required for environmental control with fluidized bed systems.

b. Fluidized bed boilers are able to remove sulfur dioxide directly in the combustor. This is accomplished by using limestone in the fluid bed. The limestone calcines to form calcium oxide (CaO) and then reacts with SO_2 to form calcium sulfate as follows:

$$CaCO_3 \longrightarrow CaO + CO_2$$
$$CaO + SO_2 + 1/2\ O_2 \longrightarrow CaSO_4$$

The ideal temperature range for desulfurization in a fluidized bed is about 1600 degrees Fahrenheit.

c. A bubbling fluidized bed boiler will require a higher calcium to sulfur ratio for control of SO_2, while the circulating fluidized bed boiler can achieve similar SO_2 removal with the Ca/S ratio of 1.5 to 2. See figure 13-8.

d. Nitrogen oxide is controlled by distribution of primary air under the bed and secondary air part way up the combustor. The staging of combustion limits the nitrogen oxide to that which is formed only by fuel-bound nitrogen. Thermally formed nitrogen oxide is negligible in the fluidized bed. See figure 13-9 for predicted nitrogen oxide emissions.

e. Several fluidized bed boiler manufacturers are now offering performance guarantees based upon experience in the bubbling, circulating, and dual bed designs.

13-5. Materials and construction

The materials used for construction of fluidized bed units are similar to those used in conventional boilers depending on the design pressure and temperature of the system.

a. In-bed tubes. The fluidized bed boilers that have in-bed tubes have experienced high erosion rates in some cases. Vertically oriented tubes are less prone to erosion than the horizontal ones. Where in-bed tubes are used, consideration should be given to use of thicker walls on the tubes and their metallurgy. Wear fins can be installed to reduce erosion. Also, some corrosion may be experienced due to the reducing atmosphere in the lower regions.

b. Fluidized bed. The fluidized bed or bottom of the combustor section varies considerably with each type of design. The method used for air distribution is important in maintaining uniform fluidization across the bed. Some units have had problems with plugging of the air openings. The bottom is castable refractory-lined on some units. Others have heat transfer tubes

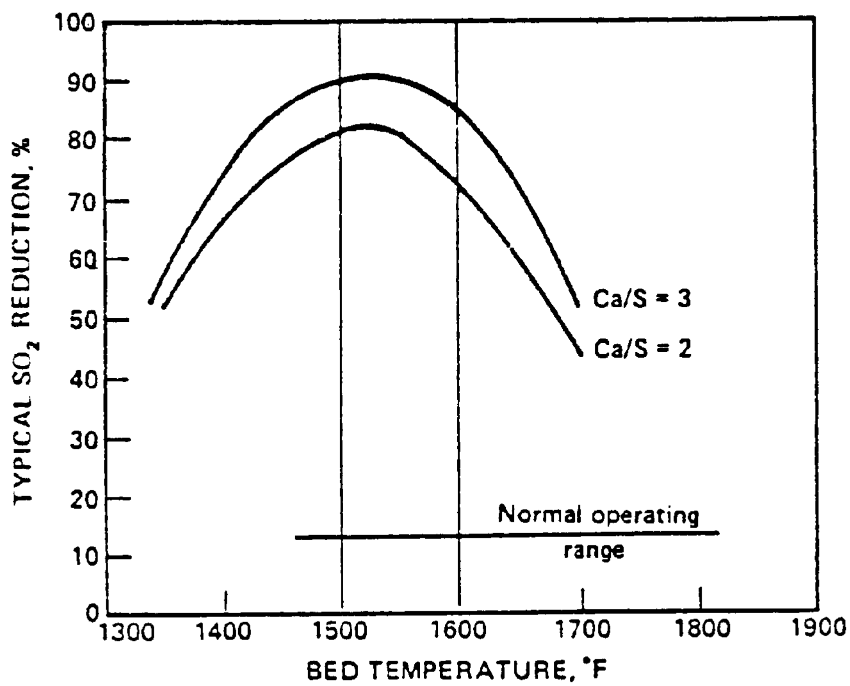


Figure 13-8. SO_2 reduction vs. combustion temperature

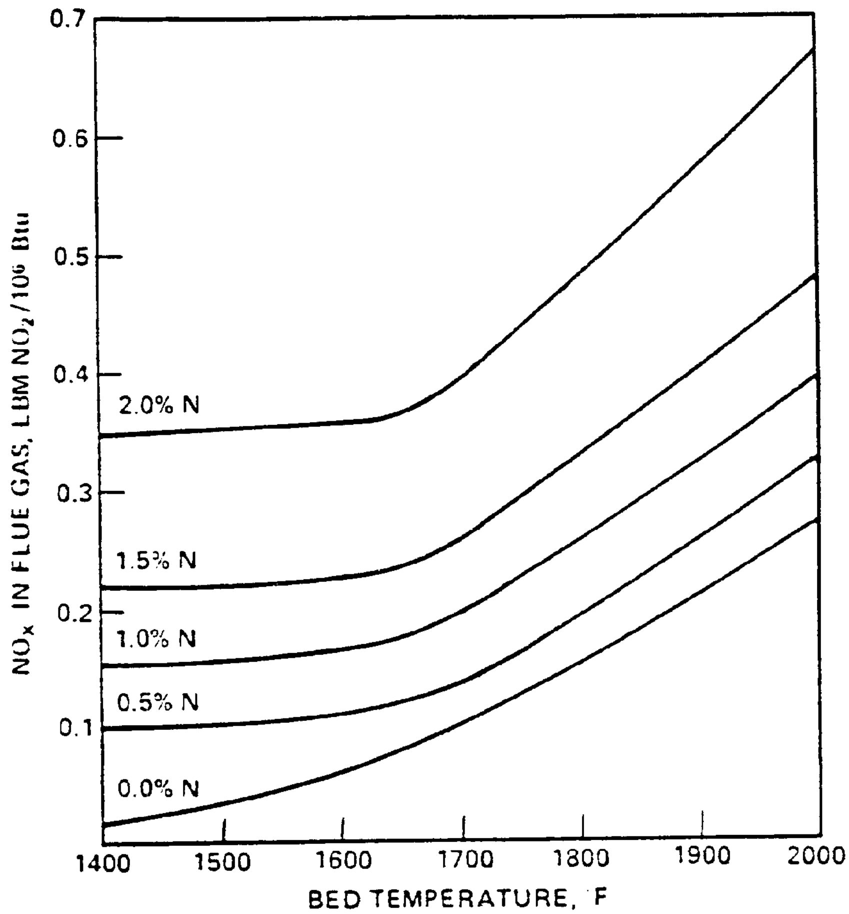


Figure 13–9. NO_x emissions vs. combustion temperature

protected with abrasion resistant refractory in regions where the gas flow changes directions.

c. Cyclone. In the circulating fluidized bed unit, the cyclone separator is lined with refractory to minimize abrasion and prevent heat losses.

d. Ash cooler. The ash cooler is also refractory lined to increase life of the unit due to abrasion of the solids being handled.

13-6. Auxiliary equipment

a. The following briefly describes the major components of auxiliary equipment for the fluidized bed boilers.

(1) Materials handling for fuel and limestone. The handling of fuel and limestone will vary depending on the source of supply and the type of delivery. Delivery is usually by truck or rail car.

(2) The conveying systems for the fuel and limestone can be either a pneumatic or a mechanical system. The mechanical system may be belt, chain, bucket, or screw conveyor, or a combination of these.

(3) Coal can be stored in open piles or storage silos. From storage, coal is fed to a crusher or dryer as required for efficient burning. Crushing of the coal is required when it is run-of-mine, for efficient burning, elimination of rocks in the bed, high moisture content, high ash content and when pneumatic conveying is necessary.

(4) Drying of the coal is recommended when the fuel moisture content exceeds fifteen percent for all fluidized bed boilers except the circulating fluidized bed boiler. The flue gas from the fluidized bed can be used for drying the fuel.

b. Coal feed stream slitter. The dual bed unit has a proprietary stream slitter which permits accurate feed of coal to multipoints under the bed for maximum combustion efficiency.

c. Startup burners. Startup burners are supplied in the bed or air ducts to heat the bed up to coal ignition temperature. The startup burner can be used for low loads. Usually it is capable of carrying about 20 percent or more of boiler capacity.

d. Fluidized bed heat exchanger. The fluid bed heat exchanger is used to cool the ash to about 750 degrees Fahrenheit. The coolant can be feedwater or any process fluid which requires heating. The metallurgy of the heat exchanger must be compatible with the fluids it is handling.

e. Flue gas clean-up for particulate. Either an electrostatic precipitator or a baghouse may be used for particulate control. Basic guidelines established for determining which type unit to use on a conventional coal fired unit may be used to select the particulate control device for a fluidized bed boiler. Electrostatic precipitators can encounter resistivity problems because of the low sulfur content in the particulate to be collected.

f. Ash-handling systems.

(1) The ash-handling systems are similar to ash-handling systems for conventional boilers. The bottom ash does have to be cooled prior to disposal. Most of the ash-handling systems are dry, and the ash can be sold for use in other products.

(2) Some potential uses of the ash are: aggregate in concrete; road base ingredients; stabilization of soil embankments; pozzolan in masonry units and mortar; agriculture and livestock feeds extender; and neutralization of spent acid wastes.

13-7. Advantages and disadvantages

a. Advantage:

(1) Low SO_2 emissions
(2) Low NO_x emission due to staged combustion and changing of the primary to secondary air ratio
(3) Only fuel bound nitrogen converted to NO_x (thermally formed NO_x is negligible)
(4) High combustion efficiency, (as high as 99 plus percent)
(5) High turn-down and load following ability
(6) Uses a variety of fuels including:
— high sulfur
— low BTU
— high ash
— low cost
— waste materials
(7) High boiler efficiency (85 to 90 plus percent)
(8) Load changes greater than 5% per minute
(9) No retractable sootblowers. Rotary sootblower may be used
(10) No slagging of coal ash
(11) Low maintenance
(12) Dry ash
(13) Broad tolerance to changes in coal quality
(14) Sulfur removal w/o need for scrubbers

b. Disadvantages:

(1) Bed turn-down capability not clear
` (2) Startup procedures more complex
(3) Control response almost instantaneous
(4) Use of partial bed slumping as load control mechanism for bubbling bed
(5) Requirement of a free-board for combustion efficiency for bubbling bed
(6) Corrosion susceptibility in bubbling bed
(7) Calcium-to-sulfur ratio greater than 2.5 causes degradation of boiler efficiency
(8) Fluidized bed is a newer technology than conventional boilers
(9) Complex under-bed fuel-feed system required for some bubbling beds